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TECHNICAL PAPER
CAA-TP-91-2

ALGORITHM FOR OPTIMIZING MOVEMENT OF EQUIPMENT AMONG POMCUS STORAGE FACILITIES (MOVER)

OCTOBER 1991

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Logistics planning for the European theater (and potentially for other theaters) provides for the prepositioning of materiel (equipment) configured to unit sets (POMCUS), such that the equipment is available at storage facilities in unit size clusters to be matched in theater with unit personnel in accordance with the theater operation plan (OPLAN). An improved means of achieving this level of planning is provided by the recently developed POMCUSITE (POMCUS Unit Siting) Model (CAA-SR-91-8), for which this publication served as a technical reference. Discussed within this technical reference is the use of a commercially available linear

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Paragraph 19 (cont)

program (HYPERLINDO) which is used to develop and evaluate a transportation matrix representing equipment overages and deficits. The matrix mathematically denotes the desired surplus and deficit facilities. Upon optimization of this matrix, the user is provided with a redistribution plan based on the minimum net travel distance for equipment transfers.

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October 1991

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ALGORITHM FOR OPTIMIZING MOVEMENT OF EQUIPMENT AMONG POMCUS STORAGE FACILITIES (MOVER)	SUMMARY CAA-TP-91-2

THE REASON FOR PRODUCING THE TECHNICAL PAPER was to provide in-depth mathematical reference material in preparation for follow-on studies relating to POMCUS (prepositioning of materiel configured to unit sets) management in Europe.

THE PROJECT SPONSOR was Director, US Army Concepts Analysis Agency. This technical paper was an internal effort.

THE OBJECTIVES OF THE TECHNICAL PAPER WERE TO:

(1) Develop a methodology for optimizing the movement of POMCUS equipment among storage locations. Results would show minimal required equipment moves on a site-by-site basis with projections of up to 8 years.

(2) Provide a means for identifying excess equipment residing in-theater which is eligible for return to CONUS (continental United States).

(3) Implement the methodology on a microcomputer, thus enabling decision-makers to try various case scenarios of interest.

THE SCOPE OF THE TECHNICAL PAPER is based on a Europe-only scenario during the 1990-1997 timeframe.

THE BASIC APPROACHES USED IN THE TECHNICAL PAPER:

(1) Define the problem, identify applicable historical data, and develop an algorithm for repositioning POMCUS materiel.

(2) Review, select, and incorporate into the methodology any appropriate commercial software package(s) which are familiar to and readily obtainable by most users.

(3) Conduct sensitivity analyses to assess algorithmic assumptions.

THE STUDY EFFORT was performed by Patti L. Rennekamp, Force Systems Directorate, US Army Concepts Analysis Agency (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-FS, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.

Tear-out copies of this synopsis are at back cover.

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CHAPTER 1

GENERAL INFORMATION

1-1. PURPOSE. The purpose of this paper is to provide a stand-alone technical reference for an algorithm developed for optimizing movement of POMCUS (prepositioned materiel configured to unit sets) equipment among storage locations. The algorithm was incorporated as the MOVER Module in the POMCUS Siting (POMCUSITE) System (see CAA Study Report CAA-SR-91-8). Portions of this description have been adapted for inclusion in the POMCUSITE Study Report and POMCUSITE System User's Manual. This paper further discusses considerations for running MOVER outside the POMCUSITE model environment. Detailed internal file descriptions and purposes are provided only in this technical paper. Special codes assigned to output results, hidden from the main POMCUSITE Model users, are discussed here, exclusively.

1-2. BACKGROUND. The US Army is projecting force structure reductions in Europe. Reductions are also projected in the requirements for theater reserve stocks and in the number of POMCUS sets. These proposed reductions, if implemented, would result in additional equipment becoming available for distribution to unit sets within the remaining POMCUS projects. At the same time, the Conventional Forces in Europe (CFE) talks may result in ceilings being established for certain classes of equipment. Also, budgetary constraints may curtail the procurement of equipment to fill POMCUS unit set shortfalls. Implementation of any of these decisions will result in changes to the actual siting requirements for some of the POMCUS projects.

1-3 MOVER'S ROLE. MOVER calculates optimal equipment moves by line item number (LIN). These equipment moves are determined on a by-site basis as necessitated by equipment redistribution and unit flag moves. Equipment short at a particular site is moved from adjacent sites possessing overages for the same item of equipment. Although the methodology was developed to support the POMCUSITE study with algorithms to redistribute POMCUS equipment among European sites, the methodology has additional features and the potential for more general applications. The methodology is also applicable to other geographical regions such as Northeast Asia, Southwest Asia, South America, or even a global concept of POMCUS equipment redistributions. Alternative costing methodologies are also discussed. For the POMCUSITE model, only the Great Circle distance between sites was used for cost. This technical paper also addresses costs incurred from variations in terrain, urban centers, tolls, etc. It also shows the user where he can enter his own costs for such items, or optionally, use the default costs of Great Circle distance.

1-4. OVERVIEW OF MOVER

a. MOVER is a deterministic time simulation which calculates constrained intratheater equipment moves among competing POMCUS sites. No priority scheme exists for these sites, and all are of equal standing. Additionally, MOVER determines excess equipment at the various sites which is eligible for return to CONUS (continental United States). Available resources consist of surplus equipment currently residing at the POMCUS sites, along with resources available through station lists, theater reserves, and CONUS.

b. Shortfalls to be filled also exist at some of the POMCUS sites. This algorithm redistributes site overages to shortfalls through use of a transportation linear program, thus arriving at the best possible solution for equipment transfers. These transfers satisfy all site requirements and do so at the minimum net travel distance in kilometers. No equipment shortages will remain following the transfers, since any materiel needed to satisfy a net shortfall is assumed to be supplied by CONUS.

c. MOVER is designed for residency on an IBM-compatible PC. It makes use of the commercial software packages HYPERLINDO (a linear, integer, and quadratic programming commercial math-stat package, large version) and FoxBASE+ (a relational data base management system). HYPERLINDO optimizes individual transportation linear programming matrices (one for each LIN) using the standard simplex method.

1-5. VERIFICATION AND VALIDATION. The basic MOVER algorithm was subjected to an independent verification and validation test procedure which was conducted external to the MOVER model design effort. That verification and validation design, as documented in the POMCUSITE Study Report, consisted of several test problems which exercised the MOVER algorithm under a variety of scenarios and algorithmic conditions. The solutions generated by MOVER were compared with anticipated outcomes predicted by the analyst from MOVER design logic and scenario considerations. All test results conformed to anticipated outcomes. See Chapter 3 for a short sample demonstration.

CHAPTER 2

OVERVIEW OF MOVER AND DESCRIPTION OF PROCESSORS

2-1. INTRODUCTION. MOVER consists of seven processors called from a DOS (disk operating system) batch file. The name and overall function of each of these processors are presented below. The individual processors are described in flowchart format.

2-2. MOVERMOD BATCH FILE. The batch file MOVERMOD.BAT is the main calling routine for the entire MOVER module. All calls to the processors discussed below are initiated from this file. MOVERMOD.BAT acts in an iterative manner, performing one iteration per processed LIN. The total number of iterations to be made is determined by the number of LINs in the unit equipment assets file (TAEDPEXT.DBF). Stepping through the calls made by MOVERMOD.BAT, there is first a call to INITFOX for initialization, followed by a call to FOXMAIN which, together with its subroutine GENMATRIX, builds the transportation matrix, and then HYPERLINDO accepts the matrix as input and outputs the optimized equipment redistribution. Lastly, MOVERMOD.BAT calls OUTREPORT to record a LIN's worth of optimized output redistribution plan (for one LIN) to the final output data base. This entire process is repeated until all LINs in the unit equipment assets file (TAEDPEXT.DBF) have been processed. Figure 2-1 shows a flowchart of the entire operation.

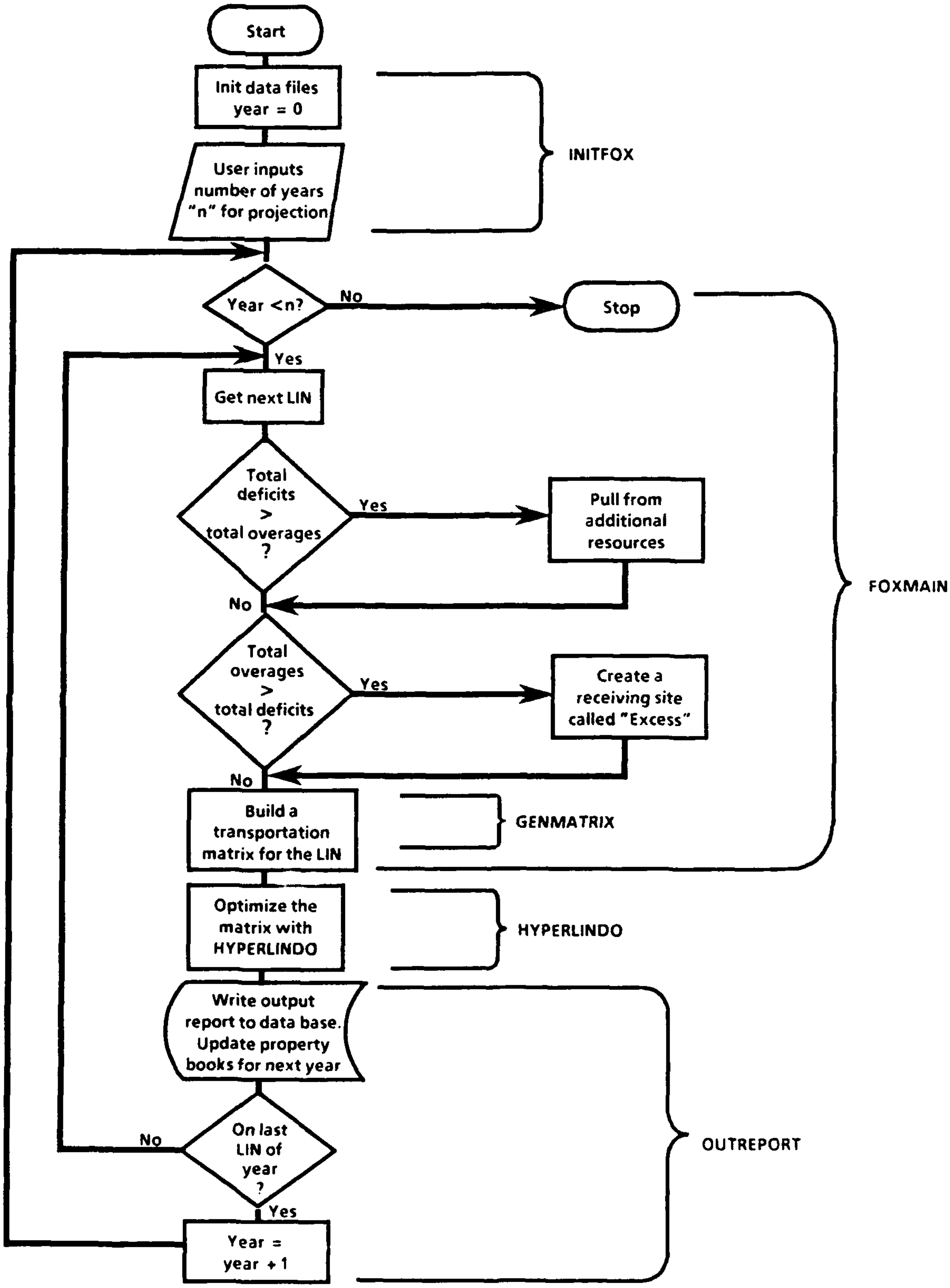

Figure 2-1. MOVERMOD Overview

2-3. INITFOX PROCESSOR. This FoxBASE program initializes all appropriate data files and accepts user input regarding the number of years for which the model is to project equipment movements (see Figure 2-2).

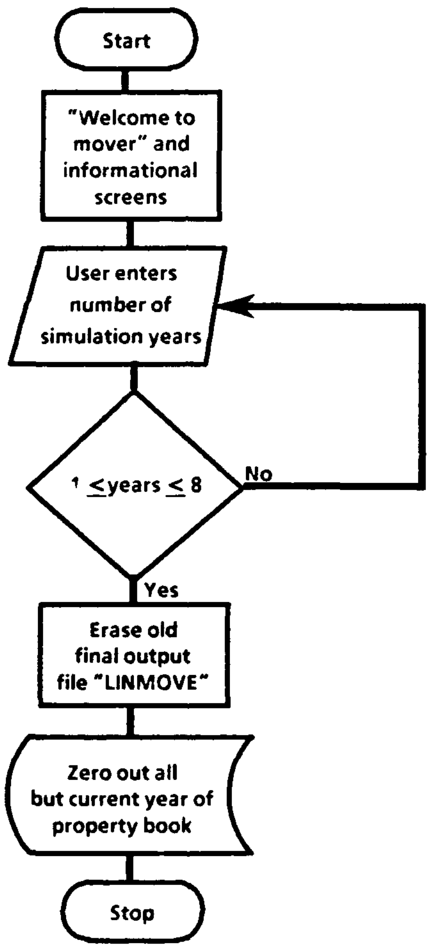

Figure 2-2. Subprocess INITFOX

2-4. FOXMAIN PROCESSOR. This FoxBASE program determines where equipment overages and deficits exist for each site and on a LIN-by-LIN basis. This is determined by comparing each site's TAEDP requirements with its property book assets. TAEDP requirements are initially presented by unit number, which must subsequently be translated into the number of the POMCUS site in which it is ensconced. These operations are in preparation for building the transportation matrix as input into the optimizing software (see Figure 2-3).

2-5. GENMATRIX PROCESSOR. This FoxBASE subroutine, called by FOXMAIN, creates the transportation matrix using data generated by FOXMAIN. Specifically, the subroutine uses the data to create decision variables by pairing each possible source (overage) site to each possible destination (deficit) site. The right-hand side of the matrix consists of the absolute quantity for overage (for overage constraints) or absolute quantity for deficit (for deficit constraints) for each appropriate site. The distance between each of these pairings is retrieved from one of the resident databases and becomes the cost associated with each decision variable. The cost (distance) associated with additional assets is set at 1. Note there is no quick and easy way to generate the transportation matrix, and it therefore must be generated "from scratch." Its format is prescribed by the HYPERLINDO software (see Figure 2-4).

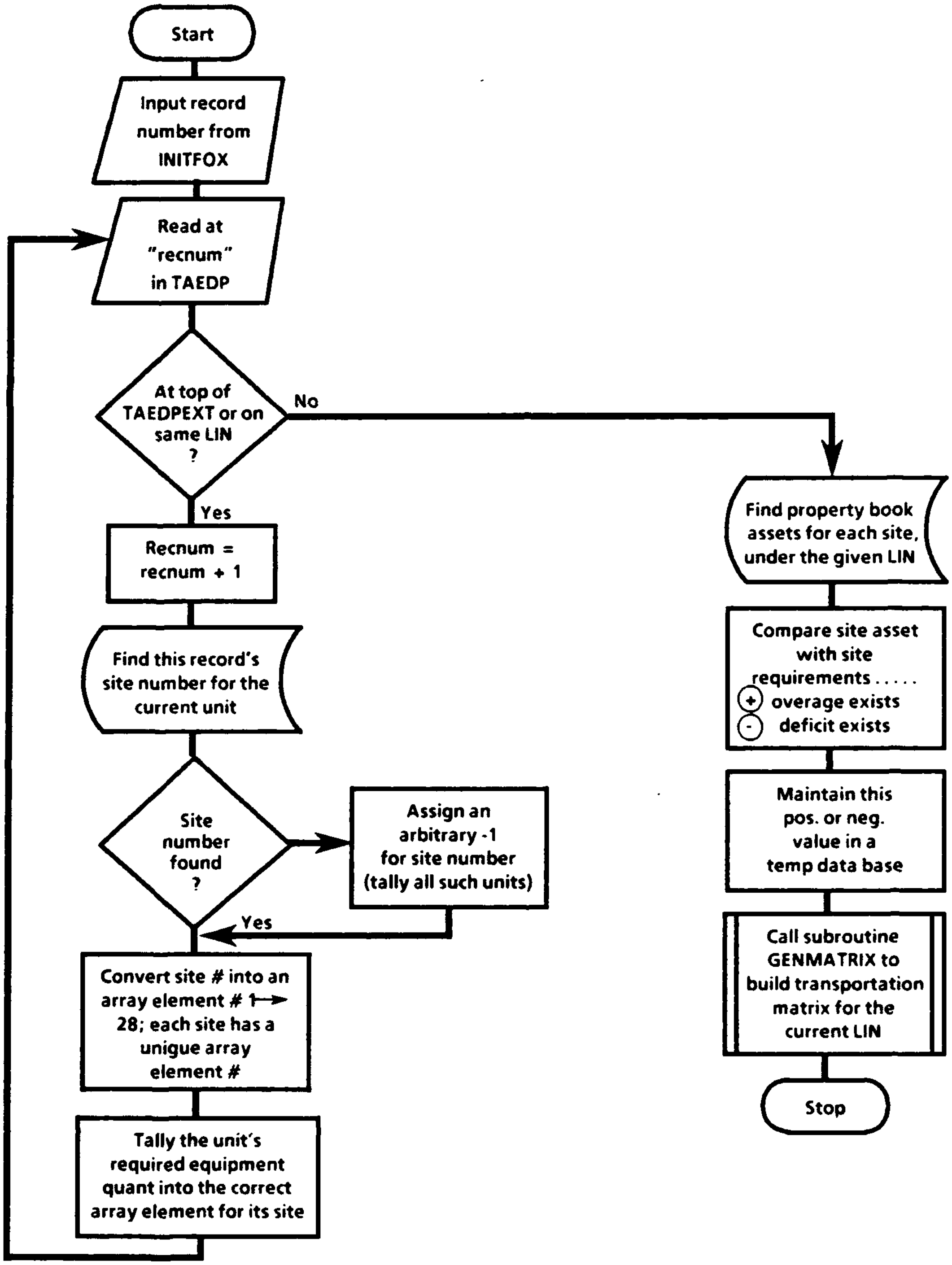

Figure 2-3. Subprocess FOXMAIN

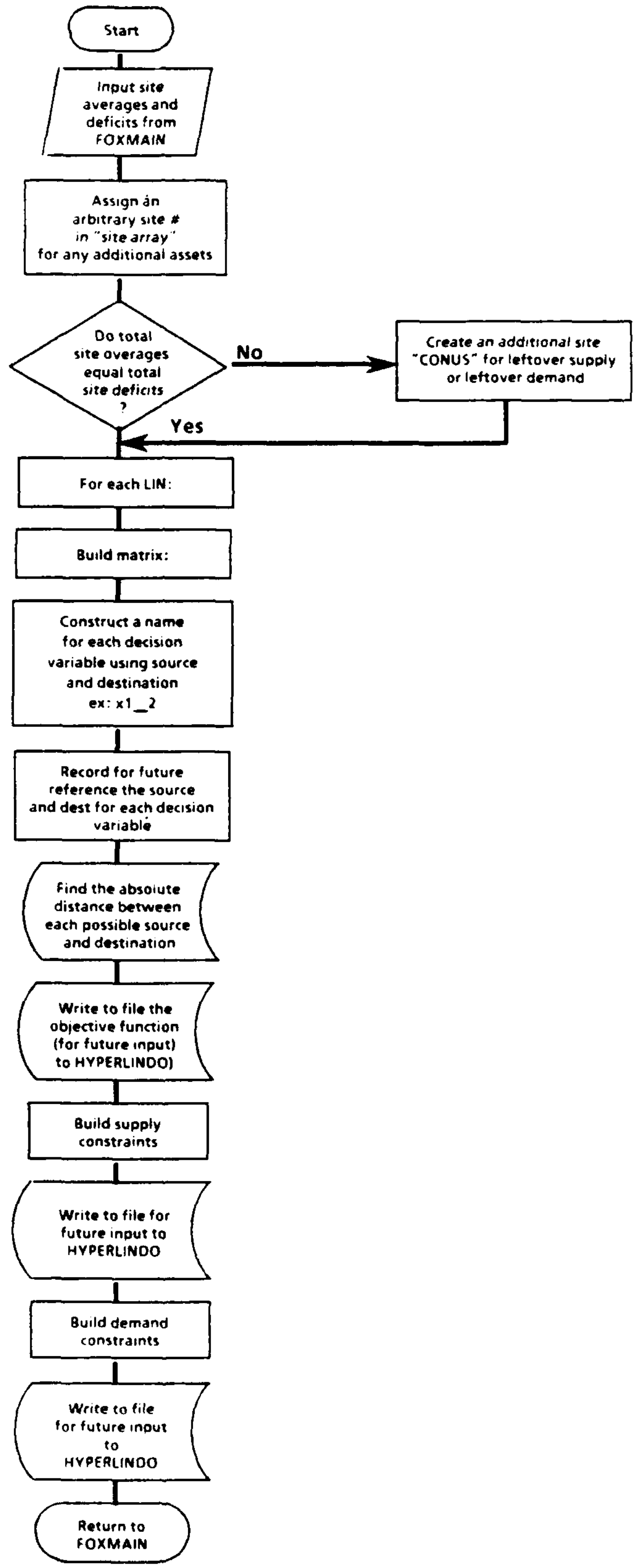

Figure 2-4. Subroutine GENMATRIX

2-6. HYPERLINDO PROCESSOR. Transparently to the user, the newly constructed transportation matrix is input into the commercial HYPERLINDO optimizing software and automatically runs without intervention. Output is written to a flat ASCII file and consists of all optimal source to destination transfers, along with the quantity associated with each transfer. The flat ASCII file is written in standard HYPERLINDO format.

2-7. OUTREPORT PROCESSOR. This FoxBASE subroutine, called by FOXMAIN, records one LIN's worth of final output to the file LINMOVE each time it is called. The final output is a synthesized version of the HYPERLINDO output which the processor converts into database format. This program also prepares for next year's equipment projections by updating the previous year's property book. Within the property book (file PBCECLIN.DBF), overage sites donating equipment have their inventory reduced for the next year. Deficit sites receiving this equipment have their inventory increased by like amount (see Figure 2-5).

2-8. OUTREP2 PROCESSOR. This FOXBASE subroutine is very similar to OUTREPORT; however, it is called at the end of the MOVER simulation and closes out the output file. Its output is the same as OUTREPORT's.

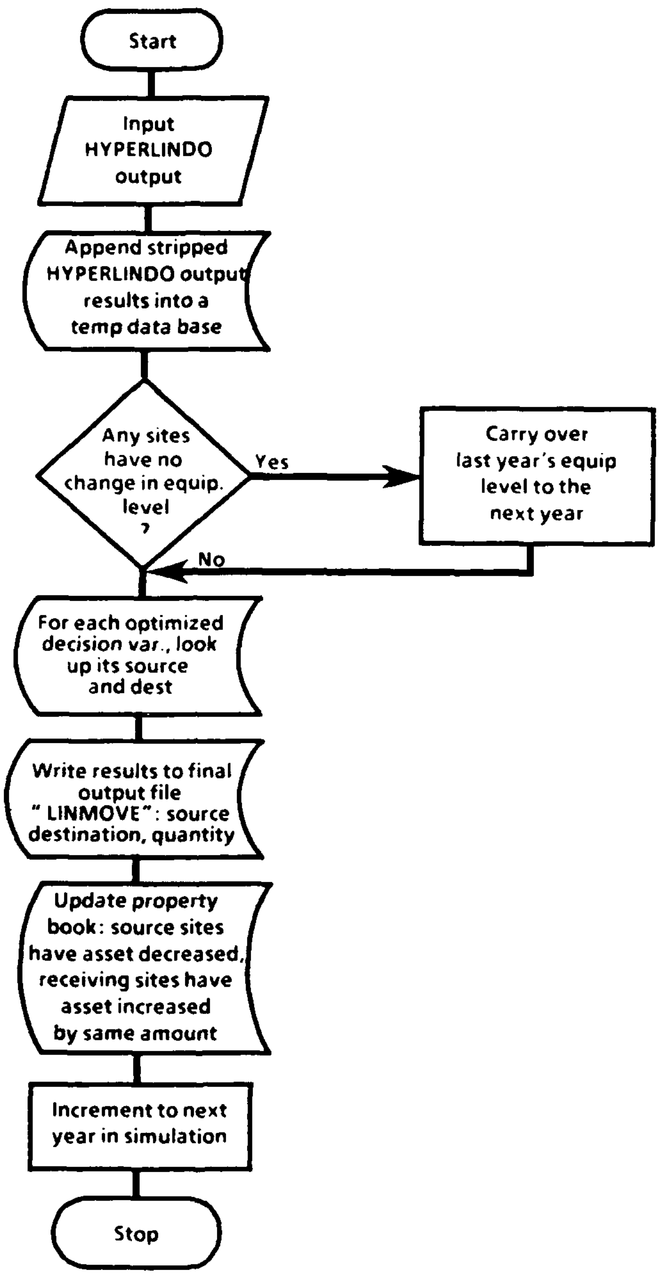

Figure 2-5. Subprocess OUTREPORT

CHAPTER 3

MOVER PROCESSING

3-1. INTRODUCTION. This chapter describes the processing carried out by MOVER in terms of four basic steps. These steps collectively identify the equipment posture of POMCUS assets and the transportation requirements associated with movement of these assets.

(1) Evaluation of Redistribution Inputs
(2) Optimization of Redistribution
(3) Evalution of Redistribution Outputs
(4) Iteration for Next Year

The four steps are implemented using the seven processors described in Chapter 2. In conducting these steps, the user is prompted for the number of years the analysis should use to project future equipment moves (the possible number of years is 1 through 8). The analysis of each of these years then builds on the previous year; and the property book is continually updated according to equipment transfers recommended by the (optimized) redistribution. The following paragraphs summarize the steps.

3-2. EVALUATION OF REDISTRIBUTION INPUTS. On a year-by-year basis and for each LIN, the TAEDP requirements and the onhand assets (as reported in the property book) are compared. This comparison provides a signed number indicating whether the sites are in overage or deficit for a given LIN. If the aggregated theater sites happen to be in overage, then additional assets will not be needed, and a separate dummy destination site called "Excess" is established. The Excess site holds all unneeded equipment aggregated from all the theater sites (that is, POMCUS sites, station list, and theater reserve). If the aggregated POMCUS sites happen to be in deficit, then resources will be pulled from the station list or the theater reserve. If these additional sources still do not satisfy equipment needs, then CONUS reserves will be tapped. The implicit assumption is made here that CONUS will always fill any remaining unfilled demand and indeed acts as an unlimited source of assets.

3-3. OPTIMIZATION OF DISTRIBUTION. The optimization involves two analytic procedures--first, the generation of a transportation matrix using a FORTRAN program, and second, the optimal redistribution of assets using a commercially available linear programming optimization package.

a. Generation of the Transportation Matrix. The general transportation problem is concerned with distributing any commodity from any group of supply centers, called sources, to any group of receiving centers, called destinations, in such a way as to minimize total distribution costs. The cost of distributing from source to destination is assumed to be proportional to the units of resource distributed. In MOVER, costs were assumed to be distances in kilometers between supply and destination sites. The POMCUS site-to-site distances are computed as point-to-point (Great Circle computation) and do not take into account urban centers or terrain conditions. These Great Circle distances should be considered as default costs. If the user is aware of faster or less costly (as in toll) routes, then he can reflect this in the

FoxBASE+ data file SITESITE.DBF. The first two fields in this file indicate a site pair of interest. The third field displays the cost for going from one site to the other site. It is here that the user can enter his own known cost. The formal definition of terms is shown in Table 3-1. Transportation model (Ref 1) is shown in Figure 3-1. An example of a transportation matrix is shown in Figure 3-2. The following convention is established for variable names in this matrix; for example, 5X3_1 indicates that the distance between sites #3 and #1 is 5 kilometers.

Table 3-1. Transportation Matrix Terminology

Term	Definition
i	Index for source sites. The source sites are POMCUS sites, station lists, theater reserve, or CONUS.
s_i	Supply of units at source i for distribution to destinations. This is the overage quantity at source site "i" for a given LIN.
j	Index for destination sites. Destination sites are either receiving POMCUS sites or the special receiving site called "Excess."
d_j	Demand for units at site j to be received from sources. This is the deficit quantity at destination site "j" for a given LIN.
x_{ij}	Referred to as the "decision variables", these are the suggested number of units to be distributed from source "i" to destination "j". This is quantity of the given LIN which is to be sent from overage site i to deficit site j.
c_{ij}	The cost per unit to distribute from source to destination. In this model, cost is the point to point distance between each possible source site to destination site pairing. CONUS resources will not be tapped unless total theater requirements exceed total theater assets, in which case only the necessary amount of equipment needed to exactly fill requirements will be taken from CONUS.
Z	Total distribution cost. This is the sum of all $C_{ij}X_{ij}$ or the total cost for moving the suggested quantities of LIN to the selected sites. Note that "Z" is actually a relative total distribution cost, due to the arbitrary costs established for additional assets.
m	Total number of source sites, i
n	Total number of destination sites, j

Minimize $$Z = \sum_{i=l}^{m} \sum_{j=1}^{n} C_{ij} X_{ij}$$

Subject to:

$$\sum_{j=l}^{n} X_{ij} = S_i \qquad \text{for } i = 1,2,\ldots m$$

$$\sum_{i=l}^{m} X_{ij} = d_j \qquad \text{for } j = 1,2,\ldots n$$

and $$X_{ij} \geq 0 \qquad \text{for all } i \text{ and } j$$

Figure 3-1. Formal Transportation Model

The following example is for LIN B12482, a 20 ton backhoe crane/shovel. Note that the parentheses in Table 3-2 represent CONUS, which is an endless source. CONUS assets were tapped because there existed a greater total deficit than overage of the LIN. For transportation models, source and destination must be equal. Table 3-3 displays the Great Circle distance between these sites.

Table 3-2. Overage and Deficit Site Values

Overage site	Quant in overage	Deficit site	Quant in deficit
3	15	1	121
9	18	4	77
17	67	5	29
20	165	6	27
22	61	15	45
(33)	(230)	16	26
		21	88
		23	143

Table 3-3. Great Circle Distances in Kilometers Between Each Possible Pairing of Sites

Pair	Distance	Pair	Distance
3 -> 1	5	3 -> 4	2
3 -> 5	5	3 -> 6	8
3 -> 15	32	3 -> 16	30
3 -> 21	39	3 -> 23	43
9 -> 1	4	9 -> 4	4
9 -> 5	3	9 -> 6	3
9 -> 15	26	9 -> 16	24
9 -> 21	33	9 -> 23	38
17 -> 1	25	17 -> 4	27
17 -> 5	24	17 -> 6	21
17 -> 15	7	17 -> 16	6
17 -> 21	17	17 -> 23	23
20 -> 1	23	20 -> 4	25
20 -> 5	22	20 -> 6	19
20 -> 15	7	20 -> 16	6
20 -> 21	17	20 -> 23	23
22 -> 1	36	22 -> 4	39
22 -> 5	39	22 -> 6	36
22 -> 15	12	22 -> 16	14
22 -> 21	3	22 -> 23	3
33 -> 1	1	33 -> 4	1
33 -> 5	1	33 -> 6	1
33 -> 15	1	33 -> 16	1
33 -> 21	1	33 -> 23	1

```
min 5x3_1+ 2x3_4+ 5x3_5+ 8x3_6+ 32x3_15+
30x3_16+ 39x3_21+ 43x3_23+ 4x9_1+ 4x9_4+
3x9_5+ 3x9_6+ 26x9_15+ 24x9_16+ 33x9_21+
38x9_23+ 25x17_1+ 27x17_4+ 24x17_5+ 21x17_6+
7x17_15+ 6x17_16+ 17x17_21+ 23x17_23+ 23x20_1+
25x20_4+ 22x20_5+ 19x20_6+ 7x20_15+ 6x20_16+
17x20_21+ 23x20_23+ 36x22_1+ 39x22_4+ 39x22_5+
36x22_6+ 12x22_15+ 14x22_16+ 3x22_21+ 3x22_23+
1x33_1+ 1x33_4+ 1x33_5+ 1x33_6+ 1x33_15+
1x33_16+ 1x33_21+ 1x33_23
```

Objective function

subject to

```
x3_1+x3_4+x3_5+x3_6+x3_15+x3_16+x3_21+x3_23 = 15
x9_1+x9_4+x9_5+x9_6+x9_15+x9_16+x9_21+x9_23 = 18
x17_1+x17_4+x17_5+x17_6+x17_15+x17_16+x17_21+x17_23 = 67
x20_1+x20_4+x20_5+x20_6+x20_15+x20_16+x20_21+x20_23 = 165
x22_1+x22_4+x22_5+x22_6+x22_15+x22_16+x22_21+x22_23 = 61
x33_1+x33_4+x33_5+x33_6+x33_15+x33_16+x33_21+x33_23 = 230
```

Supply constraints

```
x3_1+x9_1+x17_1+x20_1+x22_1+x33_1 = 121
x3_4+x9_4+x17_4+x20_4+x22_4+x33_4 = 77
x3_5+x9_5+x17_5+x20_5+x22_5+x33_5 = 29
x3_6+x9_6+x17_6+x20_6+x22_6+x33_6 = 27
x3_15+x9_15+x17_15+x20_15+x22_15+x33_15 = 45
x3_16+x9_16+x17_16+x20_16+x22_16+x33_16 = 26
x3_21+x9_21+x17_21+x20_21+x22_21+x33_21 = 88
x3_23+x9_23+x17_23+x20_23+x22_23+x33_23 = 143
```

Demand constraints

Figure 3-2. Transportation Matrix Example

This is the standard format for a transportation linear programming problem. Two points about the formulation should be made. The first is that feasibility of this problem ensures that it will always have an optimal INTEGER solution. Secondly, the model has feasible solutions only if

$$\sum_{i=1}^{m} s_i = \sum_{j=1}^{n} d_j$$

In essence, this means that source must equal demand. This condition is satisfied since CONUS will always implicitly fill any additional demand for equipment not satisfied in theater (excess demand case), and the special POMCUS site entitled "Excess" will absorb any unallocated, postoptimization equipment existing at theater overage sites (excess supply case). Using these conventions, source will always equal demand.

3-4. EVALUATION OF REDISTRIBUTED OUTPUTS

a. The data of interest to the user (see Table 3-4) is in data base format and displays the results of the equipment redistribution optimization. Listed in this output is each LIN in the TAEDP file, along with its various combinations of equipment source to destination sites. Also listed are the quantity of LIN to be distributed and the year in which this transfer is to take place. The sites are identified by three-digit identifiers designating physical POMCUS storage sites. In addition, codes with possible negative values are used to identify special locations involved in the redistribution as identified in Table 4-1.

b. Note that it is possible for a single source site to donate to several destination sites. Correspondingly, a single destination site may accept equipment from multiple donor sites. Whatever the combination of source to destination, equipment deficits at each shortage site will be completely filled, and done so with the minimum net travel distance in kilometers.

c. The redistribution is set up sequentially, so that all LINs for a given year are redistributed and displayed before moving on to the next year. Note that not all years may be displayed, depending on the user's indication of the total number of simulation years.

Table 3-4. Example of Redistribution

LIN	Source[a]	Destination[a]	Quantity	Year
B12482	3	4	15	1
B12482	9	4	18	1
B12482	17	15	45	1
B12482	17	21	22	1
B12482	20	1	17	1
B12482	20	5	29	1
B12482	20	6	27	1
B12482	20	16	26	1
B12482	20	21	66	1
B12482	22	23	61	1
B12482	33	1	104	1
B12482	33	4	44	1
B12482	33	23	82	1

[a]Positive numbers are codes for specific sites.

3-5. ITERATION FOR NEXT YEAR

a. Update of Property Book. The current year's property book must be updated before an equipment projection can be performed for the next year. The database file (PBCECLIN) which contains equipment assets by site must be readjusted to reflect the new LIN redistribution plan. POMCUS sites which lost their overages must have their inventory decremented, and sites which received this equipment must have their inventory increased by like amount. Sites which possess undistributed overage equipment are likewise decremented as their equipment is now tallied into the pseudo site "Excess." The "Excess" site holds the aggregated excess from all those sites whose overages were not redistributed to other theater sites.

b. Excess Site. It is of interest to note here that most theater sites contributing to the "Excess" site tend to be removed in distance from other overage sites. In other words, MOVER determined it to be more cost efficient to pull overage equipment from the close-in sites. The "Excess" site is established purely for bookkeeping and informational purposes. Users may decide the equipment at the "Excess" site is eligible for return to CONUS or other redistribution action. These assets are, however, not available for future redistribution. They are removed from the system.

CHAPTER 4

RUNNING MOVER

4-1. USER QUALIFICATIONS. The basic requirements for the MOVER user are:

- Ability to follow a menu-driven software package.
- Rudimentary knowledge of disk operating system (DOS) and printer commands.
- Rudimentary knowledge of FoxBASE software.

4-2. MEMORY AND DISK REQUIREMENTS. Disk storage and dynamic memory requirements for MOVER are determined in part by the HYPERLINDO and FoxBASE commercial software packages. FoxBASE consumes some 600K bytes of disk space, HYPERLINDO also consumes some 600K bytes, and the data bases which are accessed require several megabytes of storage depending upon the number of LINs and number of years processed. The system is configured such that FoxBASE and HYPERLINDO are not resident in memory at the same time; however, the user should allow for 640K of memory to be utilized. It is possible for the user to save hard disk storage by operation of the databases from diskettes; however, the input/out time invested in such a run would be extensive.

4-3. PROCESSING TIME MANAGEMENT. Other than microcomputer CPU speed, the total time required to run MOVER is a function of three factors--the number of LINs, the number of years to be examined, and the availability of a math coprocessor in the host machine. The user has the direct ability to control the first two factors, and these are discussed below. The third factor, execution with a math coprocessor, is discussed in paragraph 4-4.

a. Number of LINs. The first factor concerns the total number of LINs contained within the file TAEDPEXT. The user is advised to pare the size of this file to only those LINs which are of greatest importance. The following procedure is used to generate the LIN file when not running MOVER through the main POMCUSITE model.

- Use DOS to rename (not copy) the original and complete TAEDPEXT.DBF to another file, like MYBACKUP.DBF.
- Also at the DOS level, enter the command "FOX" to get into FoxBASE+.
- Within FoxBASE+, say "USE MYBACKUP.DBF" to pull up the file.
- Also within FoxBASE+, issue the following command: COPY TO TAEDPEXT.DBF FROM MYBACKUP.DBF FOR ALL LIN = 'DDDDDD'. Note: substitute the desired LIN for 'DDDDDD'.
- Next within FoxBASE+ say "USE TAEDPEXT".
- Finally within FoxBASE+, reindex this new TAEDPEXT.DBF by issuing the following command: INDEX ON LIN TO TAEDPEXT.

- To exit FoxBASE+, enter the command "QUIT".

- (Another method for paring the TAEDPEXT.DBF file may use the expression: "FOR ALL LIN < 'GGGGGG'"). Again, substitute the desired LIN for 'GGGGGG'.

- Once in DOS, and after finishing the run, the user is reminded to rename the files "MYBACKUP.*" back to the original TAEDPEXT.*. First, however, he must decide whether to store his new truncated version of TAEDPEXT.DBF under some other name for future runs or simply delete it. He must also make the same decision about its index file of TAEDPEXT.IDX.

b. Number of Years. The second factor which affects the length of time in which MOVER executes is the number of simulation years to be assessed for equipment moves. The user is prompted for this information early in MOVER. Not surprisingly, the fewer the years examined, the faster will be the output results. The user can enter from 1 to 8 years for this length of simulation. Seldom will more than 2 or 3 years be necessary, since only close in time periods are usually of interest.

4-4. HARDWARE CONSIDERATIONS. Users are strongly advised to run MOVER on microcomputers equipped with a math coprocessor (e.g., 80287, 80387). The 80286 is the minimum suggested coprocessor to use. Preferred would be the 80386 (with 80387) or the 80486 built-in coprocessor (not the 80486SX). Due to the voluminous amount of data synthesized, processing without a math coprocessor would be severely time-consuming. The user can, however, still run MOVER without it.

4-5. REPORT GENERATION. Final data of interest to the user is found in file LINMOVE.DBF. This file is in data base format and displays the results of the equipment redistribution optimization. Listed in this output is each LIN in the TAEDPEXT file, along with its various combinations of equipment source to destination sites. Also listed are the quantity of LIN to be distributed and the year in which this transfer is to take place. Note that it is possible for a single source site to donate to several destination sites. Correspondingly, a single destination site may accept equipment from multiple donor sites. Whatever the combination of source to destination, equipment deficits at each shortage site will be completely filled, and will be done with the minimum net travel distance in kilometers. LINMOVE is set up sequentially, so that all LINs for a given year are redistributed and displayed before moving on to the next year. Note that not all years may be displayed, depending on the user indication of the total number of simulation years. If LINMOVE needs to be preserved, the user is cautioned to do so before running a new session of MOVER. This report file is overwritten with the latest output results from the optimization. Table 4-1 lists the conventions established in LINMOVE for the various source and destination sites (postoptimization):

Table 4-1. Special Codes Assigned to Movements

Code	Type of movement
-1	Sources or destinations which had no POMCUS site number associated with their unit numbers
-2	Station list equipment used
-3	Theater reserve equipment used
-4	CONUS equipment used
-5	Equipment drawn for excess supply "sink"

Where any number other than the numbers listed in Table 2-4 appear, this indicates that the source or destination site was one of the theater POMCUS sites. For a description of this POMCUS site, look in file CECLOC1.DBF.

4-6. OUTPUT INSPECTION. In order to view the output of the optimization, the user must be able to read the file "LINMOVE" which is in data base format and resides in FoxBASE. If the user has absolutely no knowledge of FoxBASE, the following commands may be used to view this output: (Note: leave out the double quotes.)

- Within the working directory where FoxBASE and the output file resides, enter "fox". This places the user in FoxBASE.

- To pull up the final output file, enter "use linmove". The user is now looking at his final, optimized data. To scroll through this output, <Up> and <Down> arrows can be used. <Page Up> and <Page Down> keys can also be used. (Make certain the Num Lock key is toggled off.) Table 3-2 shows an excerpt from LINMOVE.

- To erase LINMOVE from the screen, hit the key <esc>. This still leaves the user in FoxBASE.

- To leave FoxBASE, enter "quit". This command returns control to DOS.

4-7. INDEXING AND YEARLY UPDATES OF DATA. Indexing of files must occur as prescribed in Appendix A. This indexing must also occur as new data becomes available, usually on a yearly basis. Prior to this indexing, however, the user should examine the structure of the new file to make certain its field name, type and length conform to the format established above. Once again, the user need not worry about this indexing if MOVER is run through the main POMCUSITE model.

4-8. ERROR HANDLING IN MOVER

a. User Input Checking. MOVER has built-in error checking for user input. If a value outside the specified range is inadvertently entered, the user will be informed of the error and asked to reenter the input. In addition to making certain his input files are in the format expressed above, the only input decision to be made by the user is the number of years for which the model should project equipment redistributions. This number must be between 1 and 8. **(NOTE:** the current year is considered to be year 0.) Any other value will make the program reprompt for correct input.

b. Data Base Value Checking. In addition to this input error checking, additional checking of values extracted from the data bases is performed. MOVER can handle zero and nonexistent values for most of the fields, and incorporates other necessary checks for nonstandard values. MOVER also establishes defaults for vague data. An example of this is units which have no associated POMCUS site number. Since the requirements of these units must be taken into consideration, all such units for a given LIN (and a given year) are aggregated under the site number of -1. The negative value of this site number is intended to make it stand out during user inspection of the output file.

4-9. MOVER LIMITATIONS AND WARNINGS

a. Limitations

(1) All newly changed files must be reindexed.

(2) The maximum number of POMCUS sites handled is 28.

b. Warnings

(1) Aborting a Run. Killing a MOVER run before completion requires aborting both the executing FoxBASE program and the DOS batch file which calls it. This process is as follows:

- With MOVER executing within FoxBASE, enter <esc> followed by the letter "C" and then "QUIT". This will take the user out of FoxBASE and return him to the calling DOS batch file.

- However, the DOS batch file continues to operate and will call FoxBASE again. To kill the DOS batch file, enter <ctrl-c>.

- Repeat process if needed to be successful.

(2) Data Corruption. The user is cautioned not to take the easy route in killing a MOVER run by rebooting in mid-execution (by hitting <ctrl><alt><del>). Such action risks corruption of the data files and is equivalent to a power surge during execution. If this occurs and the user suspects problems, the files should be recopied from backup diskettes, reindexed, and the system rerun.

APPENDIX A

MOVER DATA FILES

A-1. PERMANENT DATA FILES. MOVER has six permanent data files residing with the FoxBASE application software program. Most of these files are indexed, producing a new file with an "*.IDX" extension for each index. Table A-1 provides a synopsis of each data file, to include the names of the process(es) that access it and the overall function in MOVER. Table A-2 identifies the chacteristics of the fields in the permanent data files. The characterics identified for each field are: its definition, its type--either numeric (N) or character (C), number of columns wide, and the ".DBF" extension file(s) in which it appears. The fields in file LINMOVE.DBF are used for output. The fields in the other files are used for input. Several fields (DSITE, LIN, UICCDE) appear in both input and output files.

Table A-1. Permanent Files in MOVER

File name	Synopsis
TAEDPEXT.DBF	This data base is accessed from FOXMAIN and lists required equipment levels for each LIN, ordered by unit.
PBCECLIN.DBF	This data base serves as a LIN property book ordered by site. It is initialized by INITFOX and subsequently accessed by FOXMAIN. After optimization, updates to the file are performed by OUTREPORT and OUTREP2.
SITEUIC.DBF	This file records "SITING" selected sites for each unit, developing a correspondence between units and their encompassing POMCUS sites. The data base is accessed by FOXMAIN in order to translate each unit number into its inclusive site number.
SITESITE.DBF	This file contains site-to-site distances for each possible combination of source to destination. Such information is used to determine the distance (also known as cost in linear programming terminology) between each possible equipment source site to each possible destination site. SITESITE is accessed by GENMATRIX.
TOT-LIN.DBF	This file, accessed by GENMATRIX, contains additional assets in the form of station lists and theater reserves. Such assets are tapped when total LIN requirements exceed total LIN assets existing at the POMCUS sites. Each year's additional assets in TOT-LIN are independent of other years' assets. Example: year 1's assets cannot fill year 3's deficits.
LINMOVE.DBF	This final output data base file contains source, destination, and quantities of equipment to be transferred for each year and by LIN. The processor OUTREPORT writes to this file, one optimized LIN at a time.

Table A-2. Field Characterics in Permanent Files

Field	Type	Definition	File(s) (*.DBF)
CEC	N3	Combat equipment company which manages POMCUS site	PBCECLIN
CECODE1 to CECODE8	N4	Linkage of unit to POMCUS site for years 1-8 from SITING module	SITEUIC
DISTKM	N4	Distance in kilometers between each possible source and destination site pairing	SITESITE
DSITE	N3	Equipment destination site	SITESITE LINMOVE
LIN	C6	Line item number	TAEDPEXT PBCECLIN TOT-LIN LINMOVE
LINEC01 to LINEC08	N6	Property book assets for years 1 through 8	PBCECLIN
MCYR1	N4	Modified distribution of requirements provided by DISTRIBUTOR module	PBCECLIN
QUANT	N6	Quantity of LIN	LINMOVE
SLYR1 to SLYR8	N6	Station list equipment resources, available as assets	TOT-LIN
SSITE	N3	POMCUS, station list, theater reserve, or CONUS equipment source site	SITESITE LINMOVE
TRYR1 to TRYR8	N6	Theater reserve equipment available as assets each year	TOT-LIN
UICCDE	N4	Unit identification code	TAEDPEXT SITEUIC
YEAR	N1	Current simulation year, up to 8 max, based on number of years user wishes simulated	LINMOVE

NOTE: Type N3 denotes a numeric field of 3 position length, while C6 denotes the alpha-numeric character field of 6 position length, etc.

A-2. TEMPORARY DATA FILES. MOVER has four temporary data files which are created during execution for use as "scratch files." These files hold information which must be relayed from one processor call to the next within the MOVERMOD batch file. Such information could be, for example, the current year of the simulation, which must be available to INITFOX, FOXMAIN, and OUTREPORT. The files are of no great interest to the user and serve only as internal bookkeeping files for the duration of the execution. They are retained at the completion of the execution and are overwritten at the next execution. Table A-3 summarizes the records contained in each file.

Table A-3. Temporary Files in MOVER

File name (*.DBF)	Field	Description
TEMP1	YEAR	Current simulation year
	OLDLIN	The latest LIN read from TAEDPEXT
	RECNUM	The latest record number in TAEDPEXT
	REPFLAG	Toggle flag which indicates end of file
	UPYEAR	Toggle flag which tells the Outreport subroutine to up the current simulation year by one
	HOWLONG	Total number of simulation years specified by user
TEMP2	COMBO1	Equipment source site. COMBO1 and COMBO2 are used to associate a source and destination with each decision variable used in the optimization
	COMBO2	Equipment destination site
TEMP3	INRSLT	HYPERLINDO output results stripped of headings and titles and appended to this temporary data base
OVGDEF	OVGDEF	Signed number for each site where the sign represents an overage (+) or deficit (-) and the absolute value represents the quantity of equipment in overage or deficit

A-3. INDEXING OF FILES. Most of the aforementioned files must be indexed on at least one field. This indexing must occur before MOVER is initiated by the user. The following indicates what files to index and the command(s) which will accomplish this. If MOVER is accessed through the main POMCUSITE model, no preprocessing of data is necessary. All such operations are performed transparently to the user within POMCUSITE.

a. File TAEDPEXT.DBF

```
command:> use TAEDPEXT
command:> index on LIN to TAEDPEXT
```

b. File PBCECLIN.DBF

```
command:> use PBCECLIN
command:> index on LIN + str(cec) to PBCECLIN
```

c. File SITEUIC.DBF

```
command:> use SITEUIC
command:> index on uiccde to SITEUIC
```

d. File SITESITE.DBF

```
command:> use SITESITE
command:> index on str(ssite) + str(dsite)
```

e. File TOT-LIN.DBF

```
command:> use TOT-LIN
command:> index on LIN to TOT-LIN
```

APPENDIX B

REFERENCES

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2. User's Manual for LINDO, Third Edition, Linus Schrage, Scientific Press, Redwood City, CA, 1987

3. POMCUSITE Study Report (CAA-SR-91-8) by J. Theodore Ahrens, US Army Concepts Analysis Agency, Bethesda MD, 1991

GLOSSARY

1. ABBREVIATIONS, ACRONYMS, AND SHORT TERMS

ASCII	American Standard Code for Information Interchange
CFE	Conventional Forces in Europe
CONUS	continental United States
K	thousand
LIN	line item number
LP	linear program; linear programming
MS-DOS	Microsoft disk operating system
POMCUS	prepositioned materiel configured to unit sets
POMCUSITE	POMCUS siting alternatives

2. OTHER MODULES AND COMMERCIAL SOFTWARE

DISTRIBUTOR	module in POMCUSITE which produces a distribution plan to meet equipment needs
FoxBASE+	data base management commercial software package
HYPERLINDO	linear, integer, and quadratic programming commercial math-stat software package, large version
SITING	module in POMCUSITE which determines unit flag moves

3. DEFINITIONS

additional assets
Station list and theater reserve assets.

cost
Within the MOVER transportation matrix, this is a vector of straight-line distances between each possible source site and each possible receiving site.

CPU
central processing unit of a microcomputer.

data preprocessing
Formatting of data to make it compatible for input to MOVER.

destination site, deficit site, receiving site
POMCUS site whose equipment assets fall below the required level as dictated by the file TAEDPEXT.

decision variables
Source site to destination site pairings, over which MOVER optimizes, based over the net minimum distance between equipment transfers.

Excess site
A dummy destination site established specifically for the transportation LP model. Used when theater assets exceed theater needs with leftover supply theoretically being sent to this dummy destination. In MOVER, the Excess site also performs the role of identifying units possessing excess equipment eligible for return to CONUS.

math coprocessor
A specialized microprocessing "chip" which enables faster execution of mathematical operations.

MOVERMOD
The main calling DOS batch file for MOVER. To execute MOVER, simply enter "MOVERMOD" while residing in the appropriate directory.

property book
Residing in the file PBCFCLIN, the property book has all assets on hand at the POMCUS sites. The equipment is listed by LIN.

right-hand sides
Within the MOVER transportation matrix, this is the vector containing the equipment overage for each overage site and the absolute value of the equipment deficit for each deficit site.

source site, overage site
POMCUS site whose equipment assets listed in the property book file PBCECLIN exceed the assets required. Other source sites are station list, theater reserve, and CONUS station list individual equipment earmarked for return to CONUS.

theater reserve
Stockpiled equipment located in-theater. Used to replace destroyed equipment.

Transportation Matrix
As used in MOVER, a HYPERLINDO-compatible form of all arithmetic equations needed to perform an optimization.

unit sets
Set of all equipment authorized by TOE for a given unit.

CAA

ALGORITHM FOR OPTIMIZING MOVEMENT OF EQUIPMENT AMONG POMCUS STORAGE FACILITIES (MOVER)

SUMMARY
CAA-TP-91-2

THE REASON FOR PRODUCING THE TECHNICAL PAPER was to provide in-depth mathematical reference material in preparation for follow-on studies relating to POMCUS (prepositioning of materiel configured to unit sets) management in Europe.

THE PROJECT SPONSOR was Director, US Army Concepts Analysis Agency. This technical paper was an internal effort.

THE OBJECTIVES OF THE TECHNICAL PAPER WERE TO:

(1) Develop a methodology for optimizing the movement of POMCUS equipment among storage locations. Results would show minimal required equipment moves on a site-by-site basis with projections of up to 8 years.

(2) Provide a means for identifying excess equipment residing in-theater which is eligible for return to CONUS (continental United States).

(3) Implement the methodology on a microcomputer, thus enabling decision-makers to try various case scenarios of interest.

THE SCOPE OF THE TECHNICAL PAPER is based on a Europe-only scenario during the 1990-1997 timeframe.

THE BASIC APPROACHES USED IN THE TECHNICAL PAPER:

(1) Define the problem, identify applicable historical data, and develop an algorithm for repositioning POMCUS materiel.

(2) Review, select, and incorporate into the methodology any appropriate commercial software package(s) which are familiar to and readily obtainable by most users.

(3) Conduct sensitivity analyses to assess algorithmic assumptions.

THE STUDY EFFORT was performed by Patti L. Rennekamp, Force Systems Directorate, US Army Concepts Analysis Agency (CAA).

COMMENTS AND QUESTIONS may be sent to the Director, US Army Concepts Analysis Agency, ATTN: CSCA-FS, 8120 Woodmont Avenue, Bethesda, Maryland 20814-2797.

and Planning Meeting are available from the U. S. Naval Observatory, Time Services Department, 34th and Massachusetts Ave., N.W., Washington, DC 20392-5100. The latest volumes are also available from the National Technical Information Service, 5285 Port Royal Road, Sills Building, Springfield, VA 22161, USA.

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